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(54) Construction of DNA sequences and their use for microbial production of proteins, in particular human serum albumin.

(57) By means of reverse transcription of mRNA coding for a desired polypeptide, there is obtained a set of overlapping fragments of duplex cDNA, which together correspond to the whole mRNA molecule. The fragments have overlapping regions bearing sites for restriction enzymes, such that cutting and ligation gives DNA corresponding to the polypeptide. This is introduced into a vector in reading frame with a promoter. Transformation of a microorganism enables expression of the polypeptide.

The construction via fragments enables large molecules to be made. Thus, human serum albumin (HSA) is produced by *E. coli* transformed with plasmid pHSAl. This includes DNA made from fragments derived from reverse transcription of mRNA from human liver.

EP 0 073 646 A2

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CONSTRUCTION OF DNA SEQUENCES AND THEIR USE
FOR MICROBIAL PRODUCTION OF PROTEINS, IN
PARTICULAR HUMAN SERUM ALBUMIN

5 This invention relates to recombinant DNA technology.
It particularly relates to the application of the technology
to the production of human serum albumin (HSA) in micro-
organisms for use in the therapeutic treatment of humans.
In one aspect the invention relates to a technique for
10 producing DNA sequences encoding desired polypeptides. In
another aspect it relates to the construction of microbial
expression vehicles containing DNA sequences encoding a
protein, e.g. human serum albumin or the biologically active
component thereof operably linked to expression effecting
15 promoter systems and to the expression vehicles so
constructed. In another aspect, the present invention
relates to microorganisms transformed with

Such expression vehicles, thus directed in the expression of the DNA sequences referred to above. In yet other aspects, this invention relates to the means and methods of converting the end product of such expression to entities, such as pharmaceutical compositions, useful for the therapeutic treatment of humans. In preferred embodiments, this invention provides for particular expression vectors that are sequenced properly such that mature human serum albumin is produced directly.

In one aspect, the present invention is particularly directed to a method of preparing cDNA encoding polypeptides or biologically active portions thereof. This aspect provides the means and methods of utilizing synthetic primer DNA corresponding to a portion of the mRNA of the intended polypeptide, adjacent to a known endonuclease restriction site, in order to obtain by reverse transcription a series of DNA fragments encoding sequences of the polypeptide. These fragments are prepared such that the entire desired protein coding sequence is represented, the individual fragments containing overlapping DNA sequences harboring common endonuclease restriction sites within the corresponding overlapping sequence. This aspect facilitates the selective cleavage and ligation of the respective fragments so as to assemble the entire cDNA sequence encoding the polypeptide in proper reading frame. This discovery permits the obtention of cDNA of high molecular weight proteins which otherwise may not be available through use of usual reverse transcriptase methods and/or chemical synthesis.

The publications and other materials hereof used to illuminate the background of the invention, and in particular cases, to provide additional details respecting its practice are incorporated herein by reference, and for convenience, are numerically referenced in the following text and grouped in the appended bibliography.

(A) Human Serum Albumin

Human serum albumin (HSA) is the major protein species in adult serum. It is produced in the liver and is largely responsible for maintaining normal osmolarity in the bloodstream and functions as a carrier for numerous serum molecules (1, 2). The apparent fetal counterpart of HSA is α -fetoprotein and studies have been undertaken to compare the two as well as rat serum albumin and α -fetoprotein (3-8). The complete protein sequence of HSA has been published (9-12). The published protein sequences of HSA disagree in about 20 residues as well as in the total number of amino acids in the mature protein [584 amino acids (9); 585 (12)]. Some evidence suggests that HSA is initially synthesized as a precursor molecule (13,14) containing a "prepro" sequence. The precursor forms of bovine (15) and rat (16) serum albumin have also been sequenced.

The role or rationale for the use of albumin in therapeutic application is for the treatment of hypovolemia, hypoproteinemia and shock. Albumin currently is used to improve the plasma oncotic (colloid osmotic) pressure, caused by solutes (colloids) which are not able to pass through capillary pores. Inasmuch as albumin has a low permeability constant, it essentially confines itself to the intravascular compartment. When different concentrations of nondiffusible particles exist on opposite sides of the cell membrane, water crosses the partition until the concentrations of particles are equal on both sides. In this process of osmosis, albumin plays a vital role in maintaining the liquid content in blood.

Thus, the therapeutic benefits of albumin administration reside primarily for the treatment of conditions where there is a loss of liquid from the intravascular compartment, such as in surgical operations, shock, burns, and hypoproteinemia resulting in edema. Albumin is also used for diagnostic applications in which its nonspecific ability to bind to other proteins makes it useful in various diagnostic solutions.

Presently, human serum albumin is produced from whole blood fractionation techniques, and thus is not available in large amounts at competitive costs. The application of recombinant DNA technology makes possible the production of copious amounts of human serum albumin by use of genetically directing microorganisms to produce it efficiently. The present invention may enable the availability of purified HSA produced through recombinant DNA technology more abundantly and at lower cost than is now presently possible. The present invention also provides knowledge of the DNA sequence organization of human serum albumin and its deduced amino acid sequence, helping to elucidate the evolutionary, regulatory, and functional properties of human serum albumin as well as its related proteins such as alpha-fetoprotein.

More particularly, present invention provides for the isolation of cDNA clones spanning the entire sequence of the protein coding and 3' untranslated portions of HSA mRNA. These cDNA clones were used to construct a recombinant expression vehicle which directed the expression in a microorganism strain of the mature HSA protein under control of the trp promoter. The present invention also provides the complete nucleotide and deduced amino acid sequence of HSA.

-5-

Reference herein to the expression of "mature human serum albumin" connotes the microbial production of human serum albumin unaccompanied by the presequence ("prepro") that immediately attends translation of the human serum albumin mRNA. Mature human serum albumin, according to the present invention, is immediately expressed from a translation start signal (ATG), which also encodes the amino acid methionine linked to the first amino acid of albumin. This methionine amino acid can be naturally cleaved by the microorganism so as to prepare the human serum albumin directly. Mature human serum albumin can be expressed together with a conjugated protein other than the conventional leader, the conjugate being specifically cleavable in an intra- or extracellular environment. See British patent publication number 2007676A. Finally, the mature human serum albumin can be produced in conjunction with a microbial signal polypeptide which transports the conjugate to the cell wall, where the signal is processed away and the mature human serum albumin secreted.

(B) Recombinant DNA Technology

With the advent of recombinant DNA technology, the controlled microbial production of an enormous variety of useful polypeptides has become possible. Many mammalian polypeptides, such as human growth hormone and human and hybrid leukocyte interferons, have already been produced by various microorganisms. The power of the technology admits the microbial production of an enormous variety of useful polypeptides, putting within reach the microbially directed manufacture of hormones, enzymes, antibodies, and vaccines useful for a variety of drug-targeting applications.

A basic element of recombinant DNA technology is the plasmid, an extrachromosomal loop of double-stranded DNA found in bacteria oftentimes in multiple copies per cell. Included in the information encoded in the plasmid DNA is that required to reproduce the plasmid in daughter cells (i.e., a "replicon" or origin of replication) and ordinarily, one or more phenotypic selection characteristics, such as resistance to antibiotics, which permit clones of the host cell containing the plasmid of interest to be recognized and preferentially grown in selective media. The utility of bacterial plasmids lies in the fact that they can be specifically cleaved by one or another restriction endonuclease or "restriction enzyme", each of which recognizes a different site on the plasmid DNA. Thereafter heterologous genes or gene fragments may be inserted into the plasmid by endwise joining at the cleavage site or at reconstructed ends adjacent to the cleavage site. (As used herein, the term "heterologous" refers to a gene not ordinarily found in, or a polypeptide sequence ordinarily not produced by, a given microorganism, whereas the term "homologous" refers to a gene or polypeptide which is found in, or produced by the corresponding wild-type microorganism.) Thus formed are so-called replicable expression vehicles.

DNA recombination is performed outside the microorganism, and the resulting "recombinant" replicable expression vehicle, or plasmid, can be introduced into microorganisms by a process known as transformation and large quantities of the heterologous gene-containing recombinant vehicle obtained by growing the transformant. Moreover, where the gene is properly inserted with reference to portions of the plasmid which govern the transcription and translation of the encoded DNA message, the resulting expression vehicle can be used to actually

-7-

produce the polypeptide sequence for which the inserted gene codes, a process referred to as expression.

Expression is initiated in a DNA region known as the promoter.

5 In the transcription phase of expression, the DNA unwinds, exposing the sense coding strand of the DNA as a template for initiated synthesis of messenger RNA from the 5' to 3' end of the entire DNA sequence. The messenger RNA is, in turn, bound by ribosomes, where the messenger RNA is translated into a
10 polypeptide chain having the amino acid sequence for which the DNA codes. Each amino acid is encoded by a nucleotide triplet or "codon" which collectively make up the "structural gene", i.e., that part of the DNA sequence which encodes the amino acid sequence of the expressed polypeptide product.

15 Translation is initiated at a "start" signal (ordinarily ATG, which in the resulting messenger RNA becomes AUG). So-called stop codons, transcribed at the end of the structural gene, signal the end of translation and, hence, the production of
20 further amino acid units. The resulting product may be obtained by lysing the host cell and recovering the product by appropriate purification from other proteins.

In practice, the use of recombinant DNA technology can express
25 entirely heterologous polypeptides - so-called direct expression - or alternatively may express a heterologous polypeptide, fused to a portion of the amino acid sequence of a homologous polypeptide. In the latter cases, the intended bioactive product is rendered bioinactive within the fused,
30 homologous/heterologous polypeptide until it is cleaved in an extracellular environment. See Wetzel, American Scientist 68, 664 (1980).

-8-

If recombinant DNA technology is to fully sustain its promise, systems must be devised which optimize expression of gene inserts, so that the intended polypeptide products can be made available in controlled environments and in high yields.

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(C) State of the Art

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Sargent et al., in Proc. Natl. Acad. Sci. (USA) 78, 243 (1981), describe the cloning of rat serum albumin messenger RNA in a series of recombinant DNA plasmids. This was done to determine the nucleotide sequences of the clones in order to study the evolutionary hypothesis of the protein product. Thus, these workers made no attempt to assemble the cDNA fragments they prepared.

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In Journal of Supramolecular Structure and Cellular Biochemistry. Supplement 5, 1981, Alan R. Liss, Inc. NY, Dugaiczky et al. report, in abstract form, their studies of the human gene for human serum albumin. They obtained cDNA fragments but there is no evidence that these workers cloned or produced the fragments for any purpose other than for studying the basic molecular biology of the α -fetoprotein and serum albumin genes.

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The present invention is based upon the discovery that recombinant DNA technology can be used to successfully and efficiently produce human serum albumin in direct form. The product is suitable for use in therapeutic treatment of human beings in need of supplementation of albumin. The product is produced by genetically directed microorganisms and thus the potential exists to prepare and isolate HSA in a more

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efficient manner than is presently possible by blood fractionation techniques. It is noteworthy that we have succeeded in of genetically directing a microorganism to produce a protein of enormous length -- 584 amino acids corresponding to an mRNA transcript upwards of about 2,000 bases.

The present invention comprises the human serum albumin thus produced and the means and methods of its production. The present invention is further directed to replicable DNA expression vehicles harboring gene sequences encoding HSA in directly expressible form. Further, the present invention is directed to microorganism strains transformed with the expression vehicles described above and to microbial cultures of such transformed strains, capable of producing HSA. In still further aspects, the present invention is directed to various processes useful for preparing said HSA gene sequences, DNA expression vehicles, microorganism strains and cultures and to specific embodiments thereof. Still further, this invention is directed to the preparation of cDNA sequences encoding polypeptides which are heterologous to the microorganism host, such as human serum albumin, utilizing synthetic DNA primer sequences corresponding in sequence to regions adjacent to known restriction endonuclease sites, such that individual fragments of cDNA can be prepared which overlap in the regions encoding the common restriction endonuclease sites. This embodiment enables the precise cleavage and ligation of the fragments so as to prepare the properly encoded DNA sequence for the intended polypeptide.

The work described herein involved the expression of human serum albumin (HSA) as a representative polypeptide which is heterologous to the microorganism employed as host. Likewise the work described involved use

of the microorganism E. coli K-12 strain 294 (end A, thi⁻, hsr⁻,
k⁺hsm⁺), as described in British Patent Publication No. 2055382 A.
This strain has been deposited with the American Type Culture Collection,
ATCC Accession No. 31446.

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The invention, in its most preferred embodiments, is described with
reference to E. coli, including not only strain E. coli K-12 strain 294,
defined above, but also other known E. coli strains such as E. coli B,
E. coli x 1776 and E. coli W 3110, or other microbial strains many of
10 which are deposited and (potentially) available from recognized
microorganism depository institutions, such as the American Type Culture
Collection (ATCC)--cf. the ATCC catalogue listing. See also German
Offenlegungsschrift 2644432. These other microorganisms include, for
example, Bacilli such as Bacillus subtilis and other enterobacteriaceae
15 among which can be mentioned as examples Salmonella typhimurium and
Serratia marcesans, utilizing plasmids that can replicate and express
heterologous gene sequences therein. Yeast, such as Saccharomyces
cerevisiae, may also be employed to advantage as host organism in the
preparation of the interferon proteins hereof by expression of genes
20 coding therefor under the control of a yeast promoter. (See the
copending U.S. patent application of Hitzeman et al., filed February 25,
1981 (Attorney Docket No. 100/43), assignee Genentech, Inc. et al., or the
corresponding European Application 82300949.3 which are
incorporated herein by reference.

25 Preferred embodiments of the invention will now be described
with reference to the accompanying drawings in which:

Figs. 1A and B are diagrams for use in explaining the
construction of plasmid pHSA1;

Fig. 2 shows the immunoprecipitation of bacterially
30 synthesised HSA; and

Fig. 3 shows the amino acid sequence of HSA and the
corresponding DNA sequence.

-11-

In Fig.1A, the top line represents the mRNA coding for the human serum albumin protein and below it the regions contained in the cDNA clones F-47, F-61 and B-44 described further herein. The initial and final amino acid codons of the mature HSA mRNA are indicated by circled 1 and 585 respectively. Restriction endonuclease sites involved in the construction of pHSA1 are shown by vertical lines. An approximate size scale in nucleotides is included.

The completed plasmid pHSA1 is shown in Fig.1B, with HSA coding regions derived from cDNA clones shaded as in A). Selected restriction sites and terminal codons number 1 and 585 are indicated as above. The *E. coli* trp promoter-operator region is shown with an arrow representing the direction of transcription. G:C denotes an oligo dG:dC tail. The leftmost XbaI site and the initiation codon ATG were added synthetically. The tetracycline (Tc) and ampicillin (Ap) resistance genes in the pBR322 portion of pHSA1 are indicated by a heavy line.

Figure 2 depicts the immunoprecipitation of bacterially synthesized HSA.

E. coli cells transformed with albumin expression plasmid pHSA1 (lanes 4 and 5) or control plasmid pLeIFA25 (containing an interferon α gene in the identical expression vehicle; lanes 2, 3 and 7) were grown in ^{35}S -methionine-supplemented media. Samples in lanes 2, 4 and 7 were induced for expression from the trp promoter in M9 media lacking tryptophan; samples in lanes 3 and 5

-12-

were grown in tryptophan-containing LD broth to repress the trp promoter. Each sample lane of the autoradiograph of the SDS-polyacrylamide gel presented here contains labeled protein immunoprecipitated from 0.75 ml of cells at a density of $A_{550}=1$.
5 Lanes 1 and 6 contain radioactive protein standards (BRL) whose molecular weight in kilodaltons is indicated at the left. Bacterially synthesized HSA is seen in lane 4 comigrating with the 68,000 d ^{14}C -labeled bovine serum albumin standards. Increased production of serum albumin in the induced versus repressed culture
10 of pHSAl represents higher levels of synthesis of plasmid encoded protein rather than a difference in ^{35}S -methionine pool specific activities for minimal versus rich media (data not shown). The sharp band at 60,000 d is an apparent artifact; this band is seen in both induced and repressed pHSAl and control transformants, and
15 binds to preimmune (lane 7) as well as anti-HSA IgGs (lanes 2-5). The minor 47,000 d band in lane 4 is apparently plasmid encoded and may represent a prematurely terminated form of bacterially synthesized HSA.

20 Figure 3 depicts the nucleotide and amino acid sequence of human serum albumin.

The DNA sequence of the mature protein coding and 3' untranslated regions of HSA mRNA were determined from the recombinant plasmid
25 pHSAl. The DNA sequence of the prepro peptide coding and 5' untranslated regions were determined from the plasmid P-14 (see text). Predicted amino acids are included above the DNA sequence and are numbered from the first residue of the mature protein. The preceding 24 amino acids comprise the prepro peptide. The five
30 amino acid residues which disagree with the protein sequence of HSA reported by both Dayhoff (9) and Moulon *et al.* (12) are underlined. The above nucleotide sequence probably does not extend to the true

-13-

5' terminus of HSA mRNA. In the albumin direct expression plasmid pHSAl, the mature protein coding region is immediately preceded by the *E. coli* trp promoter-operator-leader peptide ribosome binding site (36, 37), an artificial XbaI site, and an artificial initiation codon ATG; the prepro region has been excised. The nucleotides preceding HSA codon no. 1 in pHSAl read 5'-TCACGTAAAAAGGGTATCTAGATG.

Detailed Description

10 (A) Synthesis and Cloning of cDNA. Poly(A)+ RNA was prepared from quickly frozen human liver samples obtained from biopsy or from cadaver donors by either ribonucleoside-vanadyl complex (17) or guanidinium thiocyanate (18) procedures. cDNA reactions were performed essentially as described in (19) employing as primers
15 either oligo-deoxynucleotides prepared by the phosphotriester method (20) or oligo (dT)₁₂₋₁₈ (Collaborative Research). For typical cDNA reactions 25-35 µg of poly(A)+ RNA and 40-80 pmol of oligonucleotide primer were heated at 90° for 5 minutes in 50 mM NaCl. The reaction mixture was brought to final
20 concentrations of 20 mM Tris HCl pH 8.3, 20 mM KCl, 8 mM MgCl₂, 30 mM dithiothreitol, 1 mM dATP, dCTP, dGTP, dTTP (plus ³²P-dCTP (Amersham) to follow recovery of product) and allowed to anneal at 42°C for 5'. 100 units of AMV reverse transcriptase (BRL) were added and incubation continued at 42°
25 for 45 minutes. Second strand DNA synthesis, SI treatment, size selection on polyacrylamide gels, deoxy (C) tailing and annealing to pBR322 which was cleaved with PstI and deoxy (G) tailed, were performed as previously described (21, 22). The annealed mixture was used to transform E. coli K-12 strain 294
30 (23) by a published procedure (24).

(B) Screening of Recombinant Plasmids with ^{32}P -labelled Probes.

E. coli transformants were grown on LB-agar plates containing 5 $\mu\text{g}/\text{ml}$ tetracycline, transferred to nitrocellulose filter paper (Schleicher and Schuell, BA85) and tested by hybridization using a modification of the in situ colony screening procedure (25). ^{32}P -end labelled (26) oligodeoxynucleotide fragments of from 12 to 16 nucleotides in length were used as direct hybridization probes, or ^{32}P -cDNA probes were synthesized from RNA using oligo(dT) or oligodeoxynucleotide primers (19). Filters were hybridized overnight in 5X Denhardt's solution (27), 5xSSC, (1xSSC=1.5M NaCl, 0.15M Na Citrate) 50 mM Na phosphate pH 6.8, 20 $\mu\text{g}/\text{ml}$ salmon sperm DNA at temperatures ranging from 4° to 42° and washed in salt concentrations varying from 1 to 0.2xSSC plus 0.1 percent SDS at temperatures ranging from 4° to 42° depending on the length of the ^{32}P -labelled probe (28). Dried filters were exposed to Kodak XR-2 X-ray film using DuPont Lightning-Plus intensifying screens at -80°.

(C) DNA Preparation and Restriction Enzyme Analysis. Plasmid DNA was prepared in either large scale (29) or small scale ("miniprep"; 30) quantities and cleaved by restriction endonucleases (New England Biolabs, BRL) following manufacturers conditions. Slab gel electrophoresis conditions and electroelution of DNA fragments from gels have been described (31).

(D) DNA Sequencing. DNA sequencing was accomplished by both the method of Maxam and Gilbert (26) utilizing end-labelled DNA fragments and by dideoxy chain termination (32) on single

-15-

stranded DNA from phage M13 mp7 subclones (33) utilizing synthetic oligonucleotide (20) primers. Each region was independently sequenced several times.

5 (E) Construction of 5' End of Albumin Gene for Direct Expression of
HSA. 10 μ g (~16 pmol) of the ~1200 bp PstI insert of
plasmid F-47 was boiled in H_2O for 5 minutes and combined
with 100 pmol of ^{32}P -end labelled 5' primer
(dATGGATGCACACAAG). The mixture was quenched on ice and
10 brought to a final volume of 120 μ l of 6 mM Tris HCl pH 7.5, 6
mM $MgCl_2$, 60 mM NaCl, 0.5 mM dATP, dCTP, dGTP, dTTP at 0°.
10 units of DNA polymerase I Klenow fragment (Boehringer-
Mannheim) were added and the mixture incubated at 24° for 5
hr. Following phenol/chloroform extraction, the product was
15 digested with HpaII, electrophoresed in a 5 percent
polyacrylamide gel, and the desired 450 bp fragment
electroeluted. The single stranded overhang produced by XbaI
digestion of the vector plasmid pLeIF A25 (21) was filled in to
produce blunt DNA ends by adding deoxynucleoside triphosphates
20 to 10 μ M and 10 units DNA polymerase I Klenow fragment to the
restriction endonuclease reaction mix and incubating at 12° for
10 minutes. Restriction endonuclease fragments (0.1 - 1 μ g in
approximate molar equality) were annealed and ligated overnight
at 12° in 20 μ l of 50 mM Tris HCl pH 7.6, 10 mM $MgCl_2$, 0.1 mM
25 EDTA, 5 mM dithiothreitol, 1 mM rATP with 50 units T4 ligase
(N.E. Biolabs). Further details of plasmid construction are
discussed below.

(F) Protein Analysis. Two ml cultures of recombinant E. coli
30 strains were grown in either LB or M9 media plus 5 μ g/ml
tetracycline to densities of $A_{550} = 1.0$, pelleted, washed,

-16-

repelleted, and suspended in 2 ml of LB or supplemented M9 (M9 + 0.2 percent glucose, 1 μ g/ml thiamine, 20 μ g/ml standard amino acids except methionine was 2 μ g/ml and tryptophan was excluded). Each growth medium also contained 5 μ g/ml tetracycline and 100 μ Ci 35 S-methionine (NEH; 1200 Ci/mmol). After 1 hr incubation at 37°, bacteria were pelleted, freeze-thawed and resuspended in 200 μ l 50 mM Tris HCl pH 7.5, 0.12 mM NaEDTA then placed on ice for 10 minutes following subsequent additions of lysozyme to 1 mg/ml, NP40 to 0.2 percent, and NaCl to 0.35 M. The lysate was adjusted to 10 mM $MgCl_2$ and incubated with 50 μ g/ml DNase I (Worthington) on ice for 30 min. Insoluble material was removed by mild centrifugation. Samples were immunoprecipitated with rabbit anti-HSA (Cappel Labs) and staphylococcal absorbent (Pansorbin; Cal Biochem) as described (34), and subjected to SDS polyacrylamide gel electrophoresis (35).

(G) cDNA Cloning. Initial cDNA clones primed with oligo (dT) were screened by colony hybridization with both total liver cDNA (to identify abundant RNA species containing clones) and with two 32 P-labelled cDNAs primed from liver mRNA by two sets of four 11 base oligodeoxynucleotides synthesized to represent the possible coding variations for amino acids 546-549 and 294-297 of HSA. Positive colonies never contained more than about the 3' 1/2 of the protein coding region of the expected HSA mRNA sequence. (The longest of these recombinants was designated B-44.) Since existing procedures were unable to directly copy an mRNA of the expected size (~2000 bp), synthetic oligodeoxynucleotides were prepared to correspond to the antimesage strand at regions near the 5' extreme of B-44. From the nucleotide sequence of B-44, we constructed a 12 base

-17-

oligodeoxynucleotide corresponding to amino acids 369-373. This was used to prime cDNA synthesis of liver mRNA and produce cDNA clones in pBR322 containing the 5' portion of the HSA message while overlapping the existing B-44 recombinant.

5 Approximately 400 resulting clones were screened by colony hybridization with a 16 base oligodeoxynucleotide fragment located slightly upstream in the mRNA sequence we had thus far determined. Approximately 40 percent of the colonies hybridized to both probes. Many of those colonies which failed
10 to contain hybridizing plasmids presumably resulted from RNA self-priming or priming with contaminating oligo (dT) during reverse transcription, or lost the 3' region containing the sequence used for screening. "Miniprep" amounts of plasmid DNA from hybridizing colonies were digested with PstI. Three
15 recombinant plasmids contained sufficiently large inserts to code for the remaining 5' portion of the HSA message. Two of these (F-15 and F-47) contained the extreme 5' coding portion of the gene but failed to extend back to a PstI site necessary for joining with B-44 to reform the complete albumin gene.
20 Recombinant F-61 possessed this site but lacked the 5' extreme end. A three part reconstruction of the entire message sequence was possible employing restriction endonuclease sites in common with the part length clones F-47, F-61 and B-44 (Fig. 1).

25 An additional cDNA clone extending further 5' was obtained by similar oligodeoxynucleotide primed cDNA synthesis (from a primer corresponding to amino acid codons no. 175-179). Although not employed in the construction of the mature HSA
30 expression plasmid, this cDNA clone (P-14) allowed determination of the DNA sequence of the "prepro" peptide coding and 5' non-coding regions of the HSA mRNA.

The mature HSA mRNA sequence was joined to a vector plasmid for direct expression of the mature protein in E. coli via the trp promoter-operator. The plasmid pLelF A25 directs the expression of human leukocyte interferon A (IFN α 2) (21). It was digested with XbaI and the cleavage site "filled in" to produce blunt DNA ends with DNA polymerase I Klenow fragment and deoxynucleoside triphosphates. After subsequent digestion with PstI, a "vector" fragment was gel purified that contained pBR322 sequences and a 300 bp fragment of the E. coli trp promoter, operator, and ribosome binding site of the trp leader peptide terminating in the artificially blunt ended XbaI cleavage site. A 15 base oligodeoxynucleotide was designed to contain the initiation codon ATG followed by the 12 nucleotides coding for the first four amino acids of HSA as determined by DNA sequence analysis of clone F-47. In a process referred to as "primer repair", the gene-containing PstI fragment of F-47 was denatured, annealed with excess 15-mer and reacted with DNA polymerase I Klenow fragment and deoxynucleoside triphosphates. This reaction extends a new second strand downstream from the annealed oligonucleotide, degrades the single stranded DNA upstream of codon number one and then polymerizes upstream three nucleotides complementary to ATG. In addition, when this product is blunt-end ligated to the prepared vector fragment, its initial adenosine residue recreates an XbaI restriction site. Following the primer repair reaction, the DNA was digested with HpaII and a 450 bp fragment containing the 5' portion of the mature albumin gene was gel purified (see Fig. 1). This fragment was annealed and ligated to the vector fragment and to the gel isolated HpaII to PstI portion of F-47 and used to transform E. coli cells. Diagnostic restriction

endonuclease digests of plasmid minipreps identified the recombinant A-26 which contained the 5' portion of the mature albumin coding region ligated properly to the trp promoter-operator. For the final steps in assembly, the A-26 plasmid was digested with BglII plus PstI and the -4 kb fragment was gel purified. This was annealed and ligated to a 390 bp PstI, BglII partial digestion fragment purified from F-61 and a 1000 bp PstI fragment of B-44. Restriction endonuclease analysis of resulting transformants identified plasmids containing the entire HSA coding sequence properly aligned for direct expression of the mature protein. One such recombinant plasmid was designated pHSA1. When *E. coli* containing pHSA1 is grown in minimal media lacking tryptophan, the cells produce a protein which specifically reacts with HSA antibodies and comigrates with HSA in SDS polyacrylamide electrophoresis (Fig. 2). No such protein is produced by identical recombinants grown in rich broth, implying that production in *E. coli* of the putative HSA protein is under control of the trp promoter-operator as designed. To insure the integrity of the HSA structural gene in the recombinant plasmid, pHSA1 was subject to DNA sequence analysis.

(H) DNA Sequence Analysis

The albumin cDNA portion (and surrounding regions) of pHSA1 were sequenced to completion by both the chemical degradation method of Maxam and Gilbert (26) and the dideoxy chain termination procedure employing templates derived from single stranded M13 mp7 phage derivatives (32, 33). All nucleotides were sequenced at least twice. The DNA sequence is shown in Fig. 3 along with the predicted amino acid sequence of the HSA protein. The DNA sequence farther 5' to the mature HSA coding region was also determined from the cDNA clone P-14 and is included in Fig. 3.

DNA sequence analysis confirmed that the artificial initiation codon and the complete mature HSA coding sequence directly follows the E. coli trp promoter-operator as desired. The ATG initiator follows the putative E. coli ribosome binding sequence (36) of the trp leader peptide (37) by 9 nucleotides.

Translation of the DNA sequence of pHSAl predicts a mature HSA protein of 585 amino acids. Various published protein sequences of HSA disagree at about 20 amino acids. The present sequence differs by eleven residues from Moulon et al. (12), and by 28 residues from that reported in the Dayhoff catalogue (9) credited as arising primarily from Behrens et al. (10) with contributions by Moulon et al. (12). Most of these differences represent inversions of pairs of adjacent residues or glutamine-glutamic acid disagreements. Only at five of the 585 residues does our sequence differ from the residue reported by both Dayhoff (9) and Moulon et al. (12), and three of these five differences represent glutamine-glutamic acid interchanges (underlined in Figure 3). At all discrepant positions the nucleotide sequencing has been carefully rechecked and it is unlikely that DNA sequencing errors are the cause of these reported differences. The possibility of artifacts introduced by cDNA cloning cannot be ruled out. However, other likely explanations exist for the amino acid sequence differences among various reports. These include changes in amidation (affecting glutamine-glutamic acid discrimination) occurring either in vivo or during protein sequencing (38). Polymorphism in HSA proteins may also account for some differences; over twenty genetic variants of HSA have been detected by protein electrophoresis (39) but have not yet been analyzed at the

-21-

amino acid sequence level. It is also worth noting that our predicted HSA protein sequence is 585 amino acids long, in agreement with Moulon (12) but not Dayhoff (9). The difference is accounted for by the deletion (in ref. 9) of one
5 phenylalanine (Phe) residue in a Phe-Phe pair at amino acids 156-157.

When compared to the DNA sequence of a rat serum albumin cDNA clone (16) the present mature HSA sequence shares 74 percent
10 homology at the nucleotide and 73 percent homology at the amino acid level. (The rat SA protein is one amino acid shorter than HSA; the carboxy terminal residue of HSA is absent in the rat protein.) All 35 cysteine residues are located in identical
15 positions in both proteins. The predicted "prepro" peptide region of HSA shares 76 percent nucleotide and 75 percent amino acid homology with that reported from the rat cDNA clone (16). Interspecies sequence homology is reduced in the portion of the
20 3' untranslated region which can be compared (the published rat cDNA clone ends before the 3' mRNA terminus). The HSA cDNA contains the hexanucleotide AATAAA 28 nucleotides before the site of poly(A) addition. This is a common feature of eukaryotic mRNAs first noted by Proudfoot and Brownlee (40).

Pharmaceutical Compositions

25 The compounds of the present invention can be formulated according to known methods to prepare pharmaceutically useful compositions, whereby the polypeptide hereof is combined in admixture with a pharmaceutically acceptable carrier vehicle. Suitable vehicles and their formulation are
30 described in Remington's Pharmaceutical Sciences by E.W. Martin, which is hereby incorporated by reference. Such compositions will contain an

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effective amount of the protein hereof together with a suitable amount of vehicle in order to prepare pharmaceutically acceptable compositions suitable for effective administration to the host. One preferred mode of administration is parenteral.

5

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CLAIMS:

1. A method of constructing a DNA sequence encoding a polypeptide comprising a functional protein or a bioactive portion thereof, said DNA sequence being designed for insertion together with appropriately positioned translational start and stop signals into an expression vector under the control of a microbially operable promoter, comprising the steps of:
 - 10 (a) providing messenger RNA comprising the entire coding sequence of said polypeptide,
 - (b) obtaining by reverse transcription from the messenger RNA of step (a) a series of fragments of double stranded cDNA, each of said fragments
15 corresponding in sequence to a portion of said coding sequence and thus encoding a portion of said polypeptide, wherein said fragments overlap in sequence at the respective terminal regions thereof, the overlapping portions thereof
20 containing common restriction endonuclease sites, said fragments in totality comprising the entire coding sequence of said polypeptide,
 - (c) cleaving the fragments of step (b) so as to prepare corresponding fragments which, when
25 properly ligated, encode said polypeptide, and
 - (d) ligating the fragments obtained from step (c).

2. A method of constructing a vector for use in
expressing a polypeptide comprising performing the method of
claim 1 to produce a product comprising the entire coding
sequence of said polypeptide, and introducing the product
5 into a vector under proper reading frame control of an
expression promoter.

3. The method according to claim 1 or 2 wherein said
polypeptide comprises the amino acid sequence of human serum
10 albumin.

4. The method according to claim 3 wherein the poly-
peptide contains a cleavable conjugate or microbial signal
protein attached to the N-terminus of the ordinarily first
15 amino acid of said human serum albumin.

5. The method according to claim 4 wherein said cleavable
conjugate is the amino acid methionine.

20 6. A method according to any preceding claim wherein said
DNA sequence is the gene encoding human serum albumin.

7. A DNA sequence consisting essentially of a sequence
encoding human serum albumin.

25

8. A DNA sequence according to claim 7 operably linked
with a DNA vector capable of effecting the microbial

expression of said sequence so as to prepare the corresponding human serum albumin.

9. A replicable microbial expression vehicle capable, in
5 a transformant microorganism, of expressing the DNA sequence
according to claim 7.

10. A microorganism transformed with the vehicle according
to claim 9.

10

11. A fermentation culture comprising a transformed
microorganism according to claim 10.

12. The microorganism according to claim 10, obtained by
15 transforming an E. coli bacterial or a yeast strain.

13. The plasmid pHSAl.

14. An E. coli bacterial strain transformed with the
20 plasmid according to claim 13.

15. A process which comprises microbially expressing human
serum albumin in mature form.

25 16. The use of human serum albumin prepared by the process
of claim 15 for therapeutic treatment of humans or for
preparing pharmaceutical compositions useful for such
treatment.

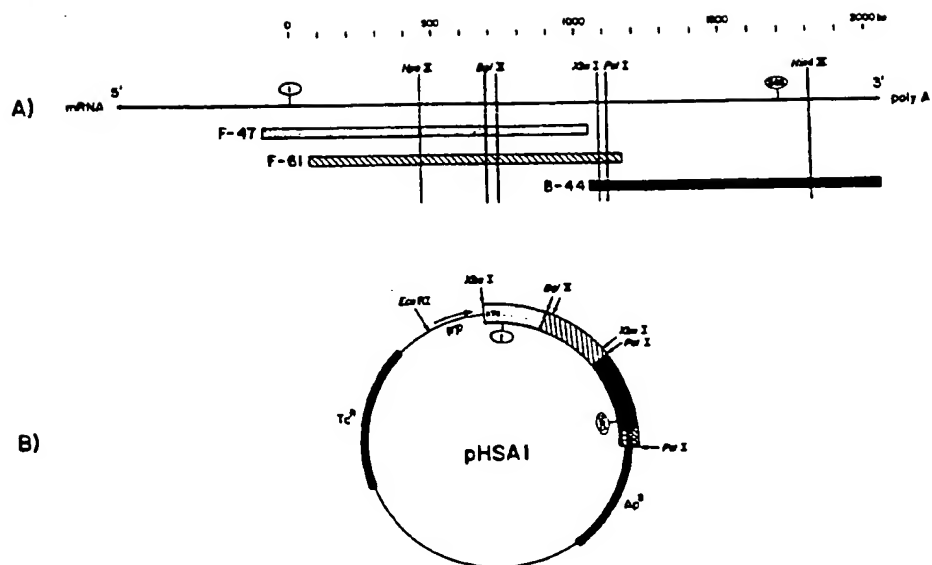


FIG. 1.

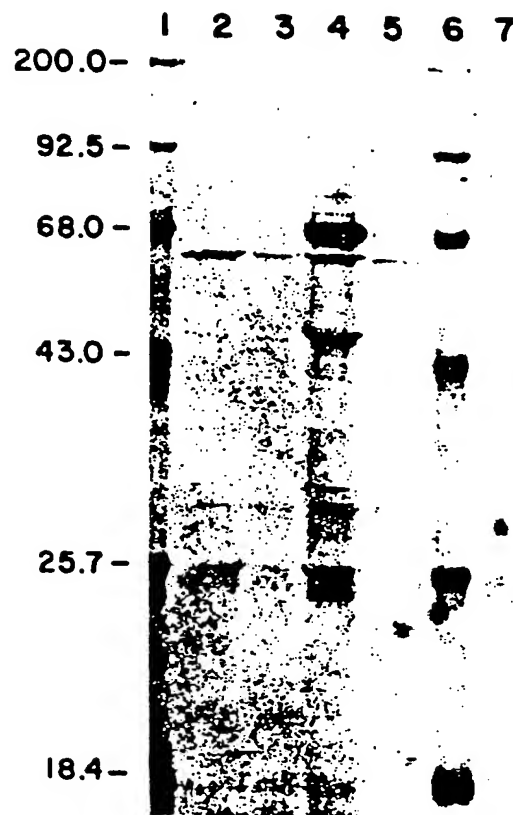
*FIG. 2.*

FIG. 3.

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